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(54) LINEARLY POLARIZED MULTI-BEAM ANTENNA BASED ON METAMATERIALS

(57) The present invention relates to a printed linearly polarized multi-beam antenna based on metamaterial technology. It consists of a circular metasurface divided into four independent quadrants.

The antenna consists of a single dielectric support, on which a large number of elliptical patches, of a small size with respect to the wavelength, is printed, and four connectors, corresponding to the input of the four quadrants of the antenna. There is no power supply network, since the patches are surface wave powered.

The antenna pattern is obtained by means of multiple holographies, patterns obtained by means of the diffraction from a dielectric on which a surface wave travels, made on a single surface and launched by means of as many connectors or couplings in the guide. In a particular four-beam embodiment of the antenna, the combination of said patterns allows to obtain the four sum and delta signals of a monopulse.

The antenna may replace the radiating plate of monopulse antennas with a reduction in size, weight and cost, while substantially maintaining the same performance.

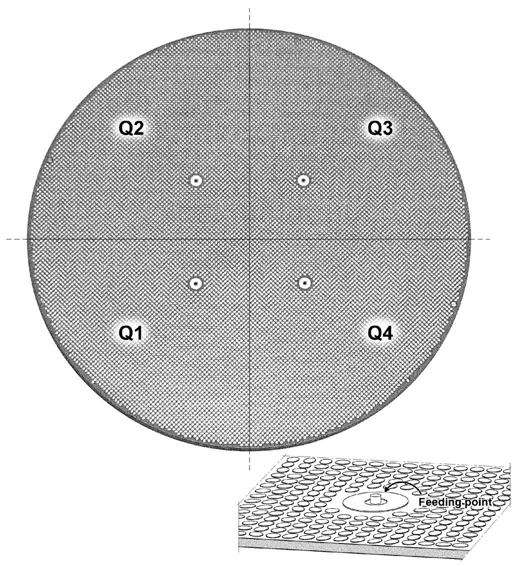


FIG.2

EP 3 902 060 A1

Description

[0001] The present invention relates to an antenna of the linearly polarized multi-beam type based on metamaterials, in particular for monopulse applications or the like.

Background art

[0002] Document [1] describes the concept of holographic antenna formed by a dielectric on which a surface wave propagates. The radiation is obtained from miniaturized metal radiators (patches) all equal in shape and size. The antenna beam is a single one. The radio frequency input is in waveguide, which entails a certain size and high costs.

[0003] Documents [2], [3] present antennas based on modulated metasurfaces, in which the radiation is obtained from a surface wave which strikes patches printed on a dielectric, having a different shape to vary the reactance thereof. The radiation pattern of the antenna is consequently controlled by acting, during the design step, on the physical parameters of these small metal elements (patches) forming the surface. The antenna beam is a single one, since the radiation is produced by the entire opening and the polarization is circular and may not be linear starting from the contributions of the specific patches according to the teachings of the articles and the rest of the prior art.

[0004] Document [4], as the two previous ones, describes antennas based on modulated metasurfaces, also assuming the possibility of manufacturing a linearly polarized single beam antenna. For this possibility, the field distribution on the opening is defined (Fig. 11a in the cited document), but no indication is given either about the relative geometry of the patches or about the pitch thereof or the area thereof, an issue which is referred to as a "non trivial" issue according to the knowledge of the field. Therefore, no experimental linearly polarized example is provided (but only circularly polarized) and the current state of the art does not allow to determine the shape, size and pitch of the patches and therefore to manufacture such linearly polarized antennas.

[0005] Document [5] presents the synthesis of multibeam antennas based on modulated metasurfaces: in a first case, it is an antenna with two opposite circularly polarized beams (right and left) and, in a second case, an antenna with four circularly polarized beams opposite two by two (in both cases, the beams are distinct and separated with different phase centers). This document also defines the field distribution on the opening, but not the geometry, distribution and size of the patches which may implement it. An experimental example is not given in this regard and the current state of the art does not allow to manufacture such antennas in the absence of a defined geometry of the patches.

[0006] All these solutions, achieved or only proposed at a general theoretical level, are not suitable for the manufacturing of linearly polarized multi-beam antennas, since they are either single-beam or circularly polarized, and are therefore not suitable for multi-beam applications, in particular for monopulse applications. On the other hand, multi-beam antennas of the conventional type have disadvantages in terms of size, weight and cost. Furthermore, circular polarization requires a greater transmitted power with respect to linear polarization (such as that of a simple dipole), since it distributes it on two components, of which only one is useful for monopulse application.

[0007] Document [6] presents an embodiment of a 4-quadrant monopulse antenna with a plurality of active radiating elements, called meshes, coupled to one another, whose dimensions, as it may be seen from the relative Figs. 1 and 2, are between 0.5 and 1.25 lambda. In fact, in a diameter of 5 lambdas, there are 4 elements in one plane and 10 elements in the other one. In this known antenna, all eight radiating elements of each quadrant are arranged in a non-repetitive manner and are directly coupled with one another, since they are mechanically in contact with one another. In total, the radiating elements are 32.

[0008] Document [7] discloses a realization of a 4-quadrant monopulse antenna with dual X and Ka bands. For the X band, the antenna is a classic array of waveguide slots, while for the Ka band it is a dielectric patch array superimposed on the guide array. Patches are much smaller than slots (by less than half) since they have to operate at more than double the frequency. This allows to interlace the patches with the slots, without the former covering the latter, as shown in Fig. 1 thereof. The patches are however always at least half a wavelength in dimensions, but at a much higher frequency.

[0009] The patches of each row of the Ka band array are directly connected to one another by a microstrip line, as shown in Fig. 5 thereof, in turn connected by means of an adapter to the waveguide, to a guide splitter (see Fig. 6), similar to the one for the input of the radiating guides of the slots.

[0010] Ultimately, the antenna in [7] consists of input guides for the two bands, radiating guides for the X band and patches connected to a microstrip for the Ka band.

[0011] The radiating waveguides and the input ones are added to the dielectric layer of the patches, for a total of at least three levels (layers) which may not be decoupled: in fact, the antenna in the Ka band does not operate without the presence of the first and third level; similarly, the X band antenna does not operate without the third level input waveguide.

[0012] Document [8] presents a circularly polarized multi-beam lens antenna. The antenna is an array of circularly polarized radiating elements, patches of a particular shape, and an underlying planar lens, obtained by arranging in underlying layers the same elements suitably arranged.

[0013] The antenna comprises three patch levels (upper metal patch, medium metal patch and lower metal patch, see

[0014] Fig. 5 thereof). The patches are between 0.2 and 0.4 lambda in size, although the pitch therebetween is of the order of half a wavelength. The patches are elliptical, with an I-shaped hole, and operate in circular polarization.

Object and subject-matter of the invention

[0015] It is the object of the present invention to provide a linearly polarized multi-beam antenna which solves the issues and overcomes the drawbacks of the prior art, also in terms of size, weight and cost, as well as of manufacturing complexity, while maintaining excellent cross-talk values.

[0016] It is the subject-matter of the present invention a linearly polarized multi-beam antenna according to the accompanying claims.

Detailed description of preferred exemplary embodiments of the invention

List of figures

[0017] The invention will now be described for illustrative but not limitative purposes, with particular reference to the figures of the accompanying drawings, in which:

- Figure 1 shows the distribution of the surface reactance X_{pp}, the real part of the surface impedance of an antenna according to an embodiment of the present invention;
- Figure 2 shows a possible geometry of the monopulse antenna according to an embodiment of the invention, in a front enlarged view;
- Figure 3 shows an antenna pattern graph, which shows the sum beam on the azimuth plane of an embodiment of the present invention;
- Figure 4 shows an antenna pattern graph, which illustrates the sum beam on the elevation plane of the same embodiment of Figure 3;
- Figure 5 shows an antenna pattern graph, which illustrates the delta-azimuth beam of the same embodiment of Figure 3;
- Figure 6 shows an antenna pattern graph, which illustrates the delta-elevation beam of the same embodiment of Figure 3;
- Figure 7 shows an antenna pattern graph, which illustrates the delta-delta beam of the same embodiment of Figure 3;
- Figure 8 shows a sum beam antenna pattern graph on the azimuth plane of the same embodiment of Figure 3, with a theoretical-experimental comparison;
- Figure 9 shows a sum beam antenna pattern graph on the elevation plane of the same embodiment of Figure 3, with a theoretical-experimental comparison;
- Figure 10 shows a measured and theoretical return-loss graph at the antenna inputs 1 and 2, according to the embodiment of Fig. 3 (frequencies in the Ka band around the central frequency f_0 of the antenna); and
- Figure 11 shows a graph of the mutual coupling measured between the antenna inputs, in the embodiment of Fig. 3 (frequencies in the Ka band around the central frequency f_0 of the antenna).

[0018] It is worth noting that hereinafter elements of different embodiments may be combined together to provide further embodiments without restrictions while respecting the technical concept of the invention, as those skilled in the art will effortlessly understand from the description.

[0019] The present description also makes reference to the prior art for its implementation, with regard to the detail features which are not described, such as, for example, elements of minor importance usually used in the prior art in solutions of the same type.

[0020] When an element is introduced, it is always understood that there may be "at least one" or "one or more".

[0021] When elements or features are listed in this description, it means that the finding in accordance with the invention "comprises" or alternatively "consists of" such elements.

Embodiments

[0022] The invention consists of a linearly polarized multi-beam antenna based on metamaterial technology and in particular as a modulated metasurface. The antenna may be monopulse, as a specific case of the multi-beam.

[0023] A modulated metasurface is a particular case of a leaky-wave antenna, i.e., a guiding structure in which a surface wave radiates as it propagates along the surface itself.

[0024] In a modulated metasurface the radiation is controlled by modulating the boundary conditions. Said boundary conditions are imposed by the presence on the surface of metal patches of different size and orientation, which suitably modify the surface impedance and therefore the radiation in the various points (see, for example, Fig. 1). The patches are excited by the surface wave and therefore have no direct connection to an electrical power supply.

[0025] Although below reference will always be made to monopulse antennas, all indications and considerations also apply to the more general class of multi-beam antennas.

[0026] Monopulse antennas are similar, in general construction, to conical scanning systems, although they have four distinct contemporary beams, pointed in slightly different directions. When the signals reflected by the target are received, they are amplified separately and compared with one another, generating the sum and delta signals (delta-azimuth, delta-elevation and delta-delta), from which it is possible to trace the direction of the target with respect to the boresight of the antenna.

[0027] According to an aspect of the invention, the antenna described herein comprises at least one dielectric layer (preferably a single dielectric layer), for example of a circular shape (although a rectangular shape or any other shape is possible). Preferably, the at least one dielectric layer is a single material, although it may also be multi-material, for example in different portions.

[0028] According to an aspect of the invention, the dielectric layer is functionally divided into at least four quadrants, for example, exactly four or eight quadrants. In the dielectric layer, surface waves corresponding to the channels of the four quadrants (thereby there is a "functional" division) are launched by means of corresponding pins (one conductor per quadrant). The pins (or other input system, see below) are placed close to the center of the antenna and for this reason the antenna is said to have a "central" input of a radio frequency signal. Under the at least one dielectric layer, a ground metallized layer is found, as per the prior art. The patches around the pins must be at a non-null distance from the pins (preferably, at least 0.1 times the central wavelength).

[0029] On one of the surfaces of the dielectric layer there are metal elements (patches) which are configured and adapted to vary the reactance thereof. In general, the thickness of the patches is very small with respect to the operating frequencies of the antenna, for example, of the order of one hundredth of a wavelength. Preferably, the patches are substantially elliptical, to be given an orientation direction and therefore provide a parameter on which to act to vary the surface impedance thereof (preferably, the patches are not perforated, in particular, they do not have an I-shaped hole). However, other shapes with a privileged direction of extension are possible (therefore, the patch has a surface area defined by two development directions, for example, orthogonal, one of which is greater than the other, also called "privileged direction"). Furthermore, according to an aspect of the invention, a subset of the patches (with a number of elements strictly lower than the total) may also have a shape without a privileged direction, for example a circular shape. Again, each patch may have a different shape, although, for manufacturing and design convenience, they may all be equal.

[0030] The pitch between the patches (distance between the respective centers of two closest patches, where the center of the patch is a geometric or suitably defined center) and the dimensions of the single patch (dimensions defining the area thereof) may both be of the order of one tenth of the central wavelength of the antenna. According to a different aspect of the invention, each of the pitch and the dimensions of the patch may have values between 0.01 and 0.5 times the central wavelength along each of the directions of a Cartesian reference on said antenna plane (therefore, a pitch and a dimension in one direction of the reference system, a pitch and a dimension in the other direction of the reference system). In any case, the patches must not be mechanically connected to one another. Preferably, the aforesaid values may be individually comprised between 0.05 and 0.3 times the central wavelength, more preferably between 0.1 and 0.2 times the central wavelength along each of the directions of a Cartesian reference on the dielectric. The pitch may not even have an obligatory upper limit.

[0031] The fact that the size of and the spacing between the patches may be reduced is allowed by the fact that the antenna according to the invention is a leaky-wave antenna, where the patches do not create the signal to be radiated, but perturb it. The surface wave introduced into the antenna is perturbed and thus modeled according to the needs. To this end, the patches must not touch one another under any circumstances, but must have the same general shape with some parameters which may be adjusted according to the design. Furthermore, even the excitation points of the surface wave in the quadrants must be at a non-null distance from the nearest patches, so that the surface wave is formed before it is perturbed by them.

[0032] The dielectric layer is here assumed to be planar, although it may also be curved. In the second case, there would no longer be a Cartesian reference but surface curvilinear coordinates. In the following we will talk about a superficial reference system to include both cases.

[0033] The above surface waves, encountering the patches, generate four antenna beams, of the holographic type, which, specially combined, form the four monopulse channels (sum, delta-azimuth, delta-elevation and delta-delta - i.e., the difference between the diagonal quadrants) of the linearly polarized antenna. No antenna combination network is required, since each of the four input points corresponds to a different antenna beam. A combiner may be added only if the four monopulse beams are to be generated from those of the quadrants. In fact, the monopulse beams may be obtained by combining the sum and delta of the inputs intended for the four connectors, by means of a plurality of waveguide combiners (also called "Magic Ts"), as known in the field. Alternatively, combinators may be avoided and the monopulse signals received may be digitally reconstructed, in a known manner, from the signals of the four quadrants.

[0034] The set of dielectric and metal patches forms the modulated metasurface of the antenna according to the invention.

[0035] According to an aspect of the invention, the antenna input may consist of four connectors (in any case, a number corresponding to the quadrants), one for each quadrant. According to a different aspect of the invention, the antenna input may be achieved by means of four slot couplings with a waveguide, always in a number corresponding to the quadrants. In this case, the waveguide is positioned under the ground layer adjacent to (deposited on) the dielectric and is coupled with the dielectric itself by means of a slot which crosses the wall of the guide itself and the ground layer up to the dielectric. The slot replaces the connector of the other embodiment according to the invention. In general, reference will be made to a radio frequency signal input system to encompass the two mentioned embodiments and any other solution which ensures an input of the radio frequency signal of the quadrant.

[0036] The term "quadrant" simply means a functional portion of the antenna, without limitations in geometry. Preferably, the quadrants all have the same shape and size.

[0037] From the point of view of the design of the antenna according to the invention, a fundamental parameter for obtaining the advantages indicated below with respect to the prior art is the orientation of the patches (at least of a non-null subset of the patches, for example, elliptical or with a privileged extension direction). Since the necessary radiation impedance may be calculated at each point of a particular antenna design, and since for each patch the impedance may be calculated as a function of the geometry and orientation thereof (for those patches with privileged development direction) with respect to the wave propagation direction, it is possible to determine the orientation of each patch in the final antenna. Such orientation will therefore depend on the desired antenna design and may be calculated on the basis of prior knowledge and the present technical teaching.

[0038] Of course, it is also possible to vary the axial ratio of the ellipses of the patches (or, in general, the shape of the patches), and this affects the radiation impedance. Such ratio may be varied differently for each patch or a single value may be provided for all patches. It is also possible to use a subset of patches (strictly smaller than the total set) with a ratio equal to 1 (i.e., circular, or square, according to another shape without a privileged direction), even though the orientation parameter for these is lost.

[0039] The monopulse antenna according to the invention may consist of a single-layer printed circuit with a circular shape. In general, for any form of the dielectric, the lower surface thereof is entirely metallized with the function of a ground plane, while on the upper surface thereof (also called "radiating surface", opposite to the lower surface, in particular parallel thereto) a large number of patches with the function of radiators is printed, as mentioned above. The power supply may be obtained by means of four pins connected to as many connectors, corresponding to the inputs of the four quadrants of the monopulse.

[0040] The dimensions and the pitch of the elliptical patches are of the order of a tenth of a wavelength as specified above in detail.

[0041] By means of each of the pins (or another input system, see above) a surface wave of the radial type (from the pin outwards) is launched into the substrate which, during propagation, encounters the elliptical patches. These constitute parallel impedances, which cause the radiation.

[0042] The shape and orientation of the ellipse determine the impedance of the patch and therefore the radiation amplitude and phase of each of the patches. The combination of the contributions of the numerous patches, also taking into account the pitch thereof, provides the radiation pattern of each of the quadrants.

[0043] A prototype of the antenna was designed in millimeter band with a diameter of 150 mm.

[0044] An experimental implementation of the antenna according to the invention consists of a layer of Rogers® R03006 with a thickness of 0.635 mm, with four SRI 25-130-1000-94 connectors, and on which 14,604 elliptical patches, placed at a 1.1 mm pitch, are printed. In this and other embodiments, the axial ratio of the ellipse of the patches may be between 1.5 and 2.0.

[0045] The connectors are placed at a distance of 26.4 mm from the center of the array.

[0046] The distance of the input points from the center of the array must be suitably chosen to minimize the mutual coupling between the channels.

[0047] The performance of the specific manufactured antenna may be summarized as follows:

- Gain > 27.5 dBi
- Sum beam width < 5° (Azimuth plane) /5° (elevation plane)
- Sum side lobes level < -12 dB (azimuth plane) / -18 dB (elevation plane)
- Cross-polarization < -30 dB (azimuth plane) / < -20 dB (elevation plane)
- Gain (Delta-azimuth) > 24.5 dB (> -3.5 dB with respect to the sum)
- Gain (Delta-elevation) > 24.0 dB (> -4.0 dB with respect to the sum)
- Gain (Delta-delta) > -21.5 dB (> -6.5 dB with respect to the sum)
- Delta-azimuth side lobes level < -13 dB with respect to the peak of the sum signal
- Delta-elevation side lobes level < -16 dB with respect to the peak of the sum signal
- Delta-delta side lobes level < -13 dB with respect to the peak of the sum signal.

[0048] In Figs. 3 to 7, the Simulated Patterns of the MMW band antenna are shown.

[0049] Fig. 3 shows the sum pattern (Σ) on the azimuth plane (i.e., with angle φ = 45-225° in polar coordinates) which has a beam width of 4°, side lobes at -13 dB, gain of 28 dBi and cross-polarization levels below -33 dB.

[0050] Fig. 4 shows the sum pattern on the elevation plane (i.e., with angle φ = 135-315° in polar coordinates) which has a beam width of 4°, side lobes at -18 dB, gain of 28 dBi and cross-polarization levels below -23 dB.

[0051] Fig. 5 shows the delta-azimuth pattern (i.e., with angle φ = 45-225° in polar coordinates) which has side lobes at -13 dB, gain of 25 dBi at -3 dB from the peak of the sum pattern, null depth of over -25 dB and cross-polarization levels below -33 dB.

[0052] Fig. 6 shows the delta-elevation pattern (i.e., with angle φ = 135-315° in polar coordinates) which has side lobes at -16 dB, gain of 24.5 dBi at -3.5 dB from the peak of the sum pattern, null depth of over -33 dB and cross-polarization levels below -22 dB.

[0053] Fig. 7 shows the delta-delta pattern which features side lobes at -15 dB, gain of 21.5 dBi at -6.5 dB from the sum, null depth of over -33 dB, and cross-polarization levels below -33 dB.

[0054] These patterns are perfectly adequate for the monopulse function.

[0055] Figs. 8 and 9 show comparisons of the sum beam antenna pattern on the simulated and experimental azimuth and elevation plane.

[0056] The measured beam width is between 4.0 and 4.1°, perfectly in line with the theoretical data. The measured gain is also congruent with the theoretical one of 27.9 dB.

[0057] Fig. 10 shows the return-loss measured at two antenna ports compared with the calculated one. The figure shows an experimental trend which follows the theoretical one very well, also with regard to the two resonances presented by the antenna.

[0058] Finally, Fig. 11 shows the mutual coupling measured between the antenna ports. The measured values are always below -30 dB, which guarantees a good decoupling between all the antenna ports.

Advantages of the invention

[0059] Modulated metasurface antennas have already been presented in the literature, although, as mentioned above, they are single-beam antennas. Only a recent publication [5] presents the possibility of creating multi-beam antennas and analyzes issues and possible solutions, highlighting the possibility of manufacturing a multi-beam antenna, but only circularly polarized and in a theoretical manner.

[0060] The solution of the present invention provides an antenna with a performance very similar to that of an antenna with conventional technology.

[0061] However, this is the first application of the technology of metamaterials and modulated metasurfaces with linearly polarized multi-beam antennas, which may therefore be usefully employed for monopulse antennas.

[0062] The advantages are also related to the dimensions and bulkiness of the antenna and, above all, to the cost and manufacturing simplicity of the antenna itself, which consists of a single printed circuit. Furthermore, linear polarization allows a higher gain with respect to metasurfaces solutions existing in the prior art, where circular polarization is not required.

[0063] On the other hand, the fact of using a single substrate as in all the known cases mentioned above may entail a serious crosstalk issue between the different channels used, which would introduce an important disturbance, while the solution of the present invention does not involve such an issue by virtue of the specific features thereof. The very constitution of the antenna allows to maintain an excellent performance in terms of isolation between channels.

References

[0064]

[1] M. ElSherbiny, A. E. Fathy, A. Rosen, G. Hayes, S.M. Perlow "Holographic Antenna Concept, Analysis and Parameters", IEEE Transactions on Antennas and Propagation, vol. 52, no. 3, March 2004, pp. 830-839

[2] G. Minatti, M. Faenzi, E. Martini, F. Caminita, P. De Vita, D. Gonzalez-Ovejero, M. Sabbadini, S. Maci, "Modulated Metasurface Antennas for Space: Syntehsis, Analysis and Realizations", IEEE Transactions on Antennas and Propagation, vol. 63, no. 4, April 2015 , pp. 1288-1300

[3] P. De Vita, G. Guida, M. Bandinelli, G. Minatti, M. Sabbadini, E. Martini, S. Maci, A. Freni, "Metasurface-by-design: an emerging concept for antennas and beam forming networks", 2013 IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC), 9-13 Sept. 2013, pp. 980-983

[4] G. Minatti, F. Caminita, E. Martini, M. Sabbadini, S. Maci, "Synthesis of Modulated-Metasurface Antennas with amplitude, phase and polarization control", IEEE Transactions on Antennas and Propagation, vol. 64, no. 9, September 2016, pp. 3907-3919

[5] D. Gonzales-Ovejero, G. Minatti, G. Chattopadhyay, S. Maci, "Multibeam by Metasurface Antennas", IEEE Transactions on Antennas and Propagation, Vol. 65, No. 6, June 2017, pp. 2923-2930

[6] US 4 376 938 A1 (TOTH JOHN F ET AL) filed on 15 March 1983

[7] US 5 831 581 A1 (KEOUGH SHAUN M [US]) filed on 3 November 1998

[8] CN 109 742 556 A1 (UNIV SOUTHEAST) filed on 10 May 2019

[0065] Hereto, we have described the preferred embodiments and suggested some variants of the present invention, but it is understood that those skilled in the art can make modifications and changes without departing from the respective scope of protection, as defined by the appended claims.

Claims

1. A linearly polarized leaky-wave multi-beam antenna, operating in a single frequency band, having a radio frequency signal input and a radiating antenna surface with a predefined central wavelength, the multi-

beam antenna comprising:

- at least one layer of dielectric material, with an upper surface and a lower surface opposite to each other, the at least one layer of dielectric material being functionally divided into at least four quadrants, said upper surface constituting the radiating antenna surface;
- a metal layer on the lower surface;
- for each of said at least four quadrants, a respective radio frequency signal input system;
- said upper surface has a plurality of metal patches, wherein each patch extends for a first respective length along a respective first direction and for a second respective length along a respective second direction;

the antenna being **characterized in that**:

- said respective input system is configured to launch a surface wave of the radial type in the layer of dielectric material;
- said respective input system is placed at a predefined non-null distance from the metal patches;
- said first respective length and said second respective second length are between 0.05 and 0.3 times the predefined central wavelength;
- the patches of said plurality of metal patches are arranged on said upper surface so that:
    - the distance between consecutive patch centers in any direction is between 0.05 and 0.3 times the predefined central wavelength;
    - none of the metal patches are electrically connected to any of the other patches; and
- the patches belonging to a non-null subset of said plurality of metal patches are such that said first respective length is different from said second respective length.

2. An antenna according to claim 1, wherein said distance between consecutive patch centers and said first respective length and second respective length have values between 0.05 and 0.2 times the predefined central wavelength.

3. An antenna according to one or more of claims 1 to 2, wherein the antenna has a circular shape.

4. An antenna according to one or more of claims 1 to 3, wherein the patches of said plurality of patches are printed on said upper surface.

5. An antenna according to one or more of claims 1 to 4, wherein said respective radio frequency signal input system comprises an electrical connector in contact with said dielectric material.

6. An antenna according to one or more of claims 1 to 4, wherein said respective radio frequency signal input system comprises a waveguide positioned under said metal layer and coupled to the layer of dielectric material by a slot passing through a wall of the waveguide itself and the metal layer.

7. An antenna according to one or more of claims 1 to 6, wherein all the patches of said plurality of metal patches are such that said first respective length is different from said second respective length.

8. An antenna according to one or more of claims 1 to 7, wherein said non-null subset of said plurality of metal patches consists of patches having a substantially elliptical shape.

9. An antenna according to claim 8, wherein said elliptical shape has an axial ratio comprised between 1.5 and 2.0.

10. An antenna according to one or more of claims 1 to 9, of the monopulse type.

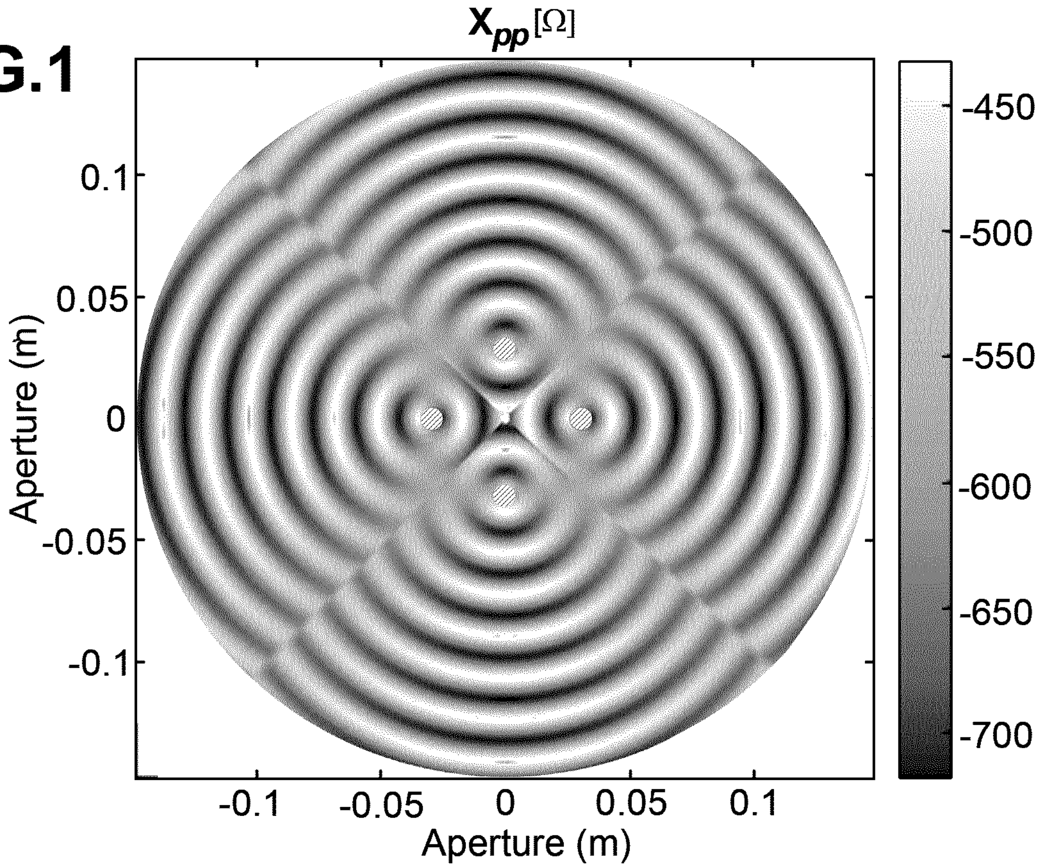
11. An antenna according to one or more of claims 1 to 10, wherein a center is defined on the antenna and the respective radio frequency signal input systems are placed at a substantially equal distance from said center.

12. An antenna according to one or more of claims 1 to 11, wherein the distance between said respective input system and the metal patches is greater than or equal to 0.1 times the predefined central wavelength.

13. An antenna according to one or more of claims 1 to 12, wherein between one metal patch and the other there is a distance equal to at least 0.01 times the predefined central wavelength.

14. An antenna according to claim 13, wherein between one metal patch and the other there is a distance between 0.01 and 0.3 times the predefined central wavelength.

FIG.1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0.1
Aperture (m)
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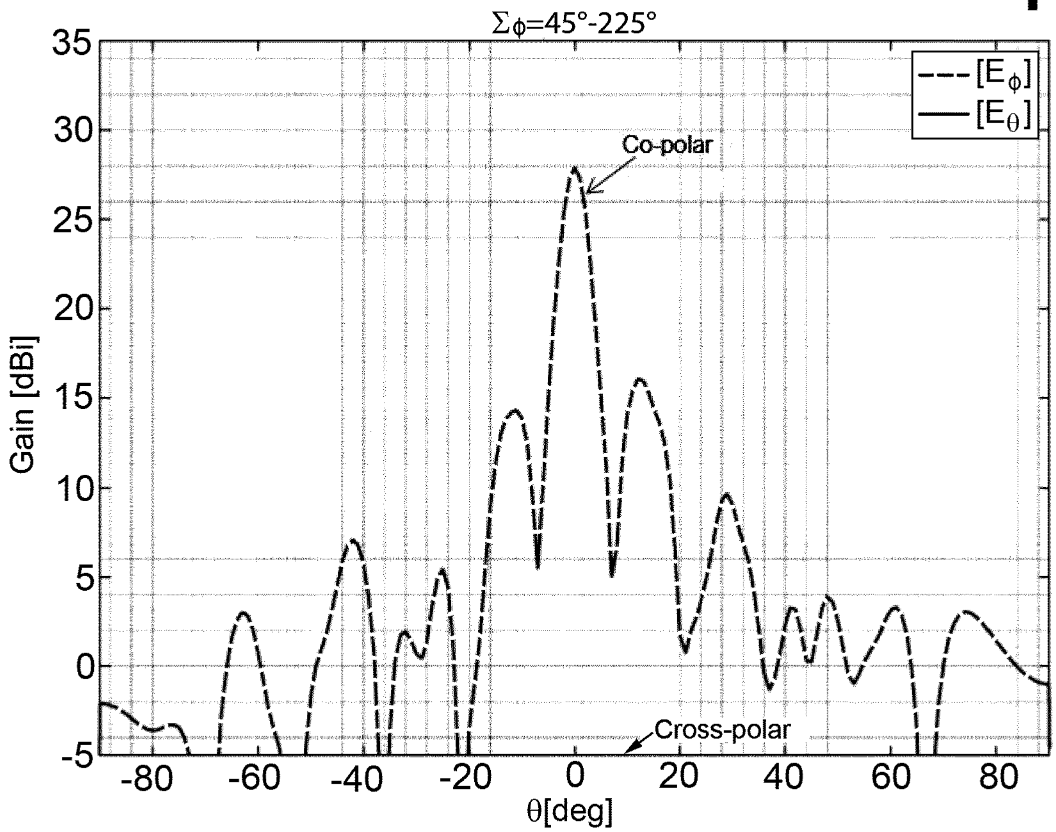
FIG.3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80
θ[deg]

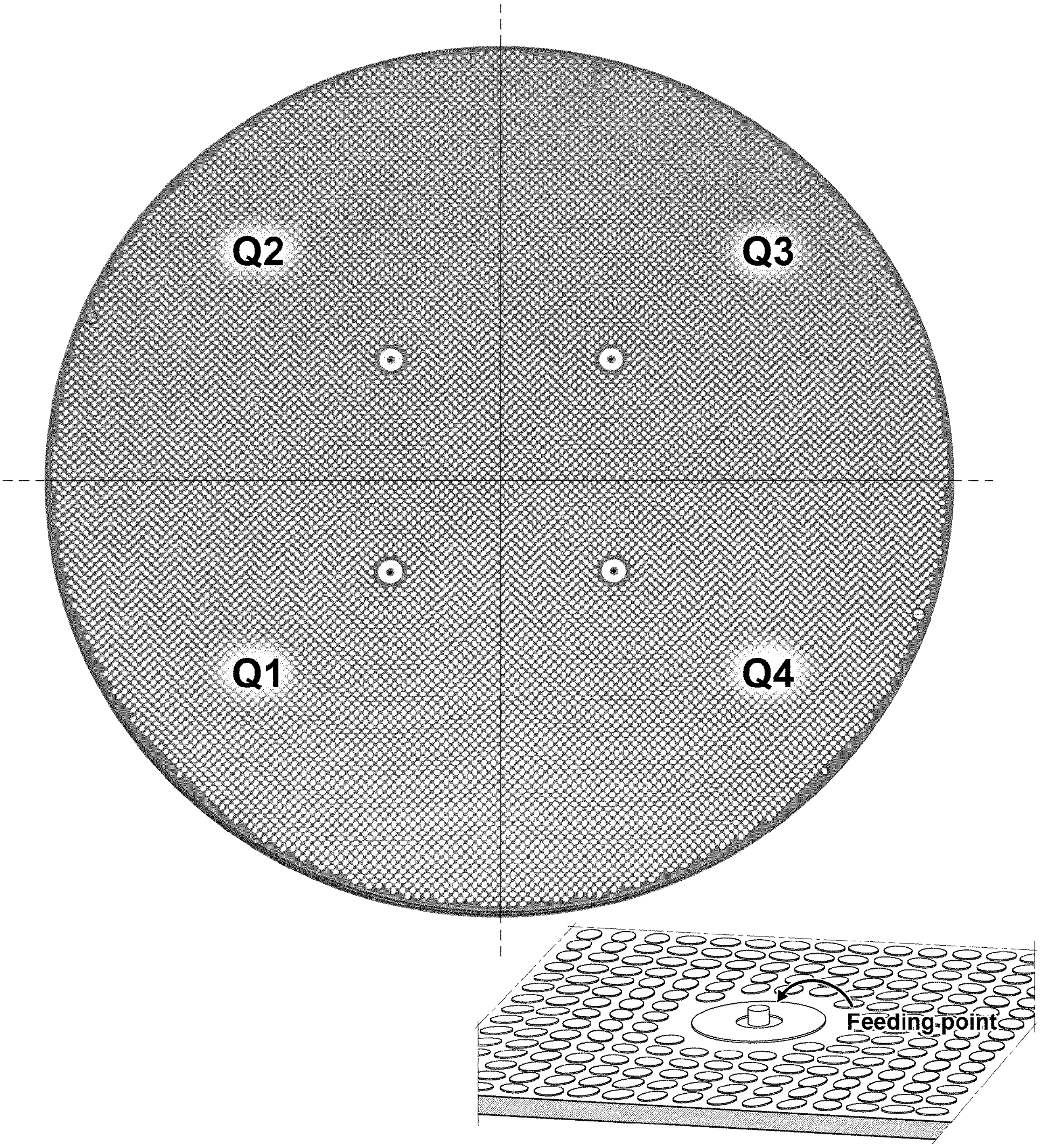


FIG.2

FIG.4

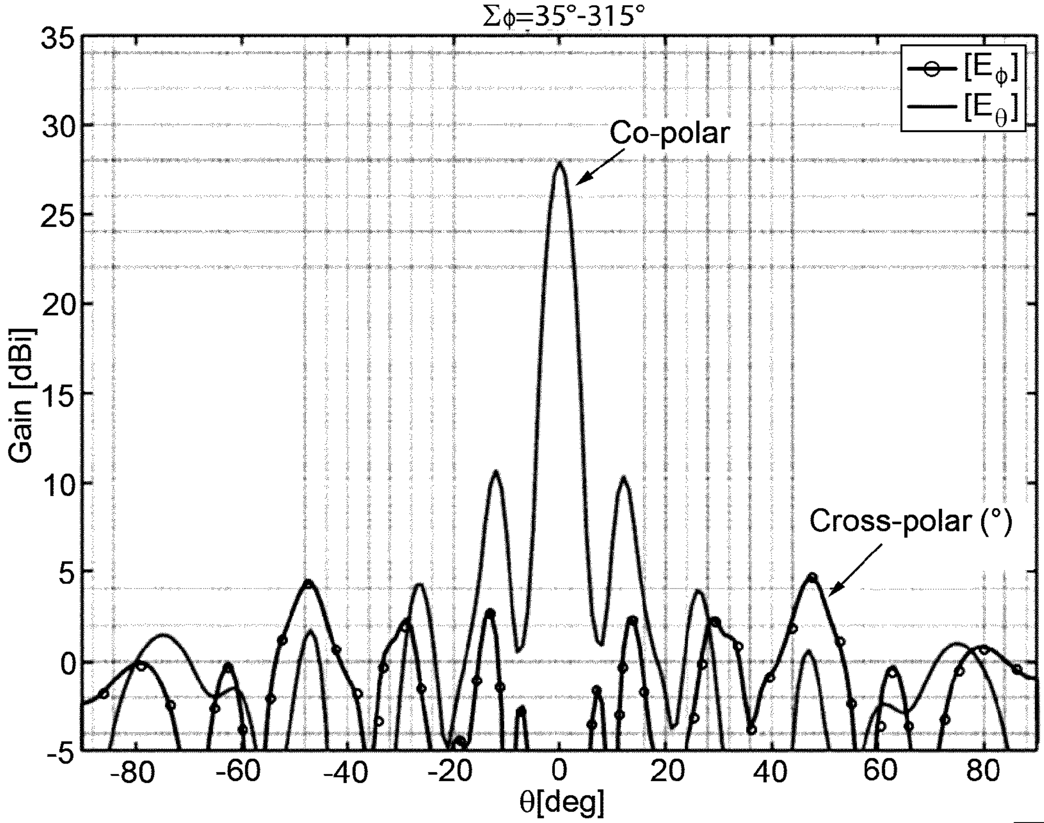

Σϕ=35°-315°
35
30
25
20
15
10
5
0
-5
Gain [dBi]
-80
-60
-40
-20
0
20
40
60
80
θ[deg]
[Eϕ]
[Eθ]
Co-polar
Cross-polar (°)

FIG.5

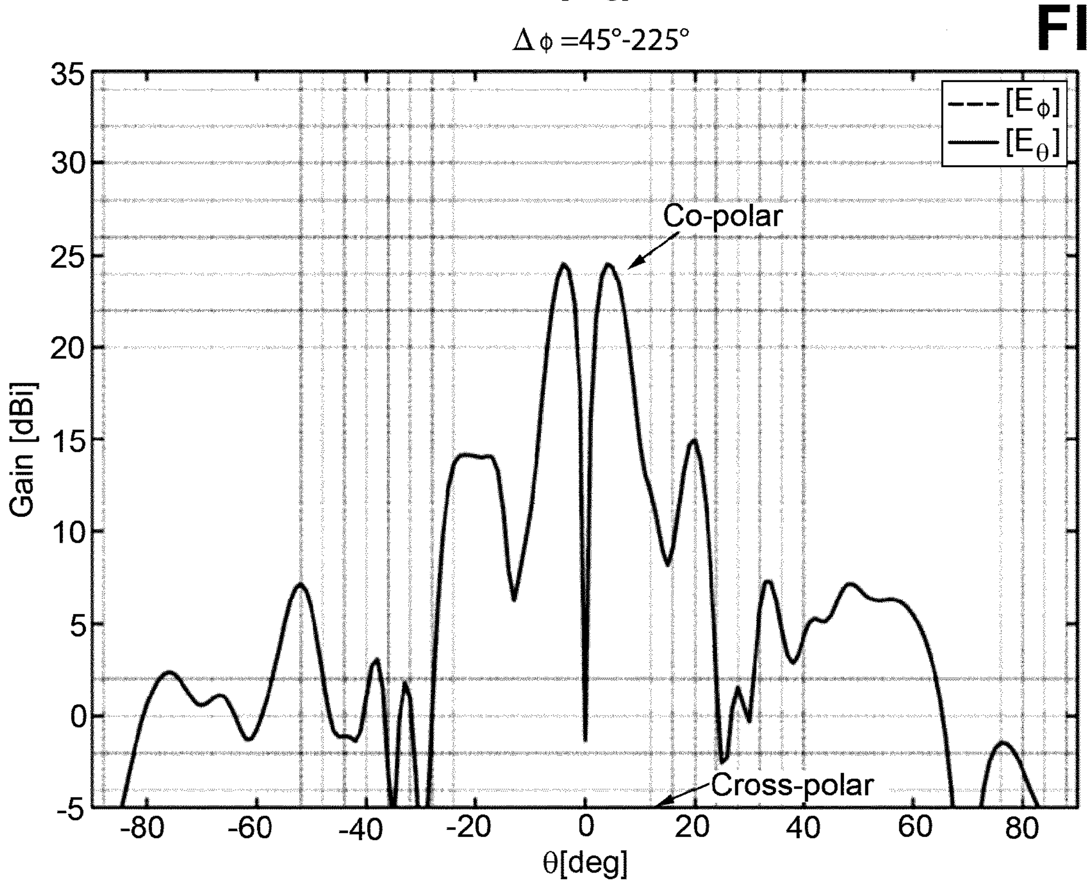

Δϕ =45°-225°
35
30
25
20
15
10
5
0
-5
Gain [dBi]
-80
-60
-40
-20
0
20
40
60
80
θ[deg]
[Eϕ]
[Eθ]
Co-polar
Cross-polar

FIG.6

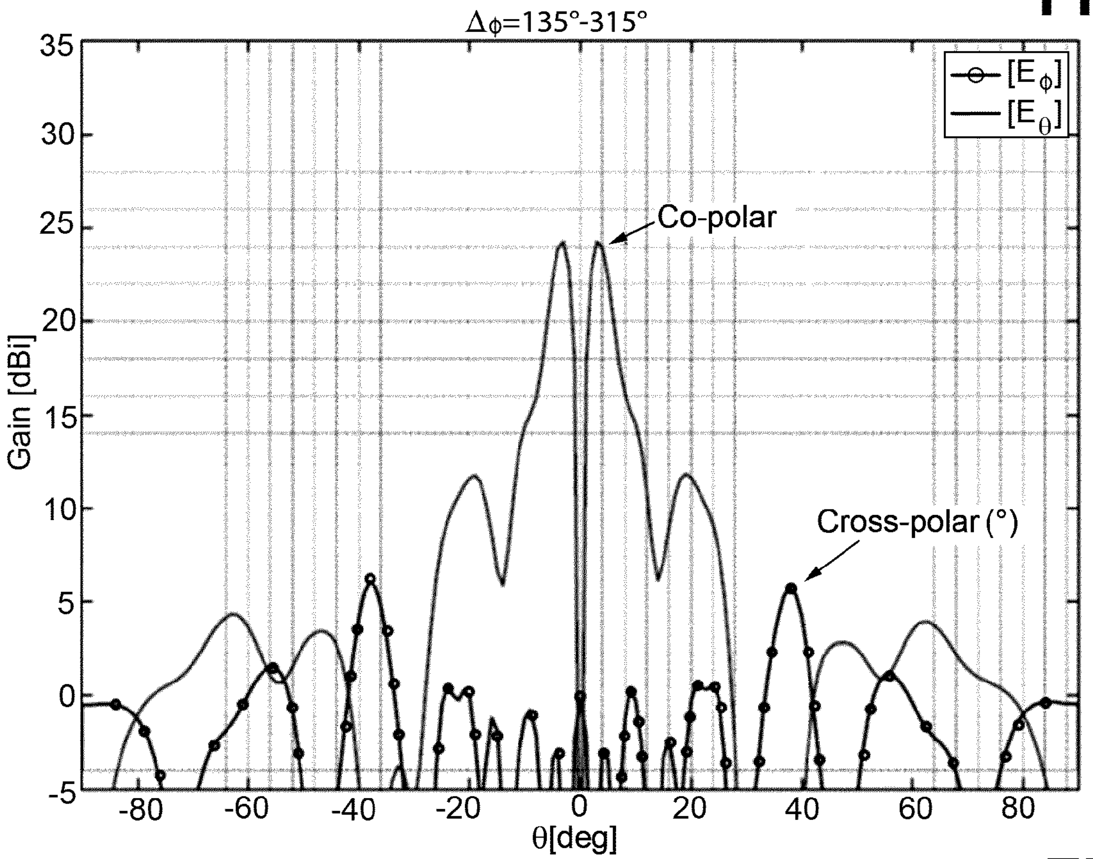
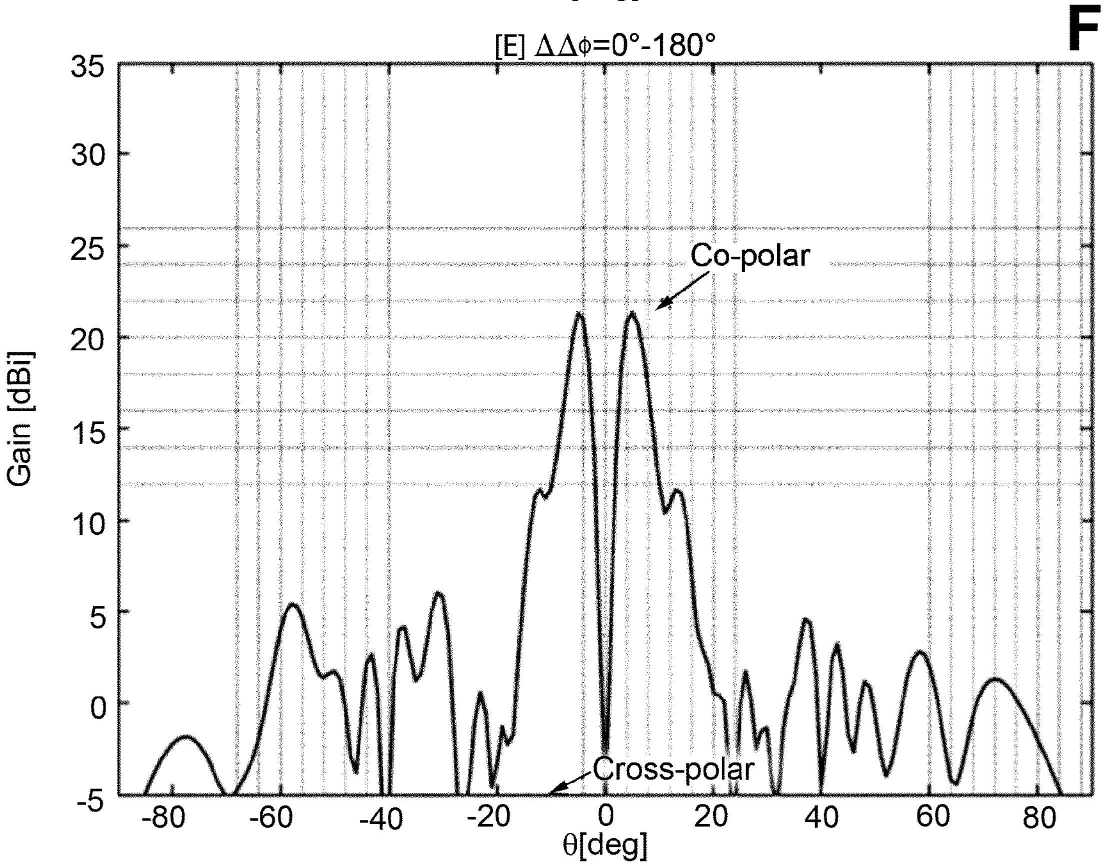

Δϕ=135°-315°
[Eϕ]
[Eθ]
Co-polar
Cross-polar (°)
Gain [dBi]
θ[deg]
35
30
25
20
15
10
5
0
-5
-80
-60
-40
-20
0
20
40
60
80

FIG.7


[E] ΔΔϕ=0°-180°
Co-polar
Cross-polar
Gain [dBi]
θ[deg]
35
30
25
20
15
10
5
0
-5
-80
-60
-40
-20
0
20
40
60
80

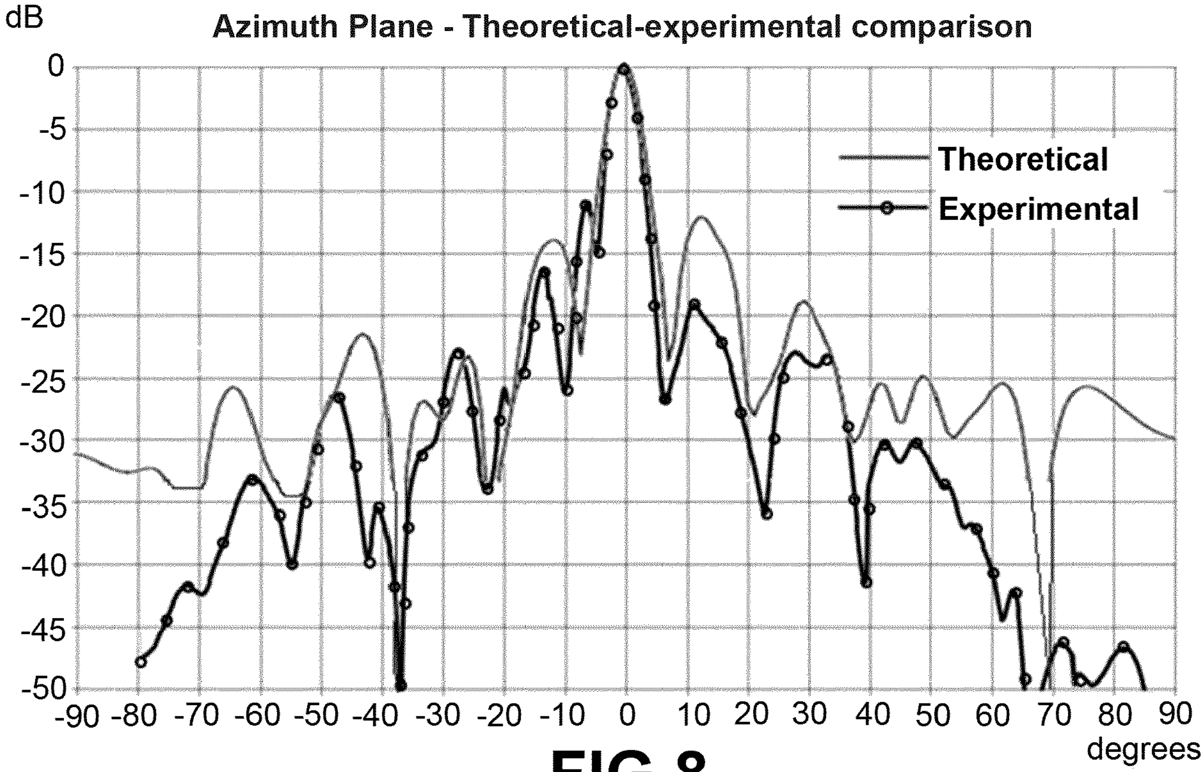

dB
Azimuth Plane - Theoretical-experimental comparison
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
Theoretical
Experimental
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
degrees

FIG.8

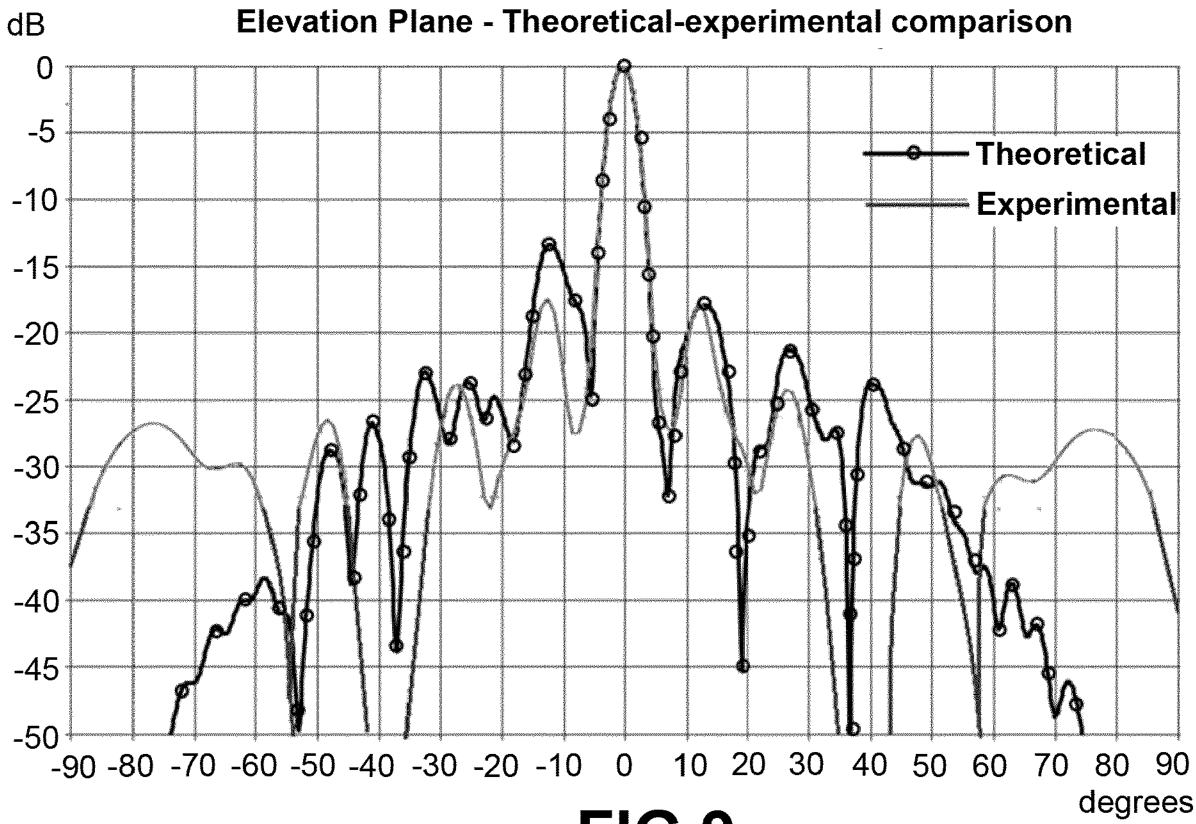

dB
Elevation Plane - Theoretical-experimental comparison
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
Theoretical
Experimental
-90 -80 -70 -60 -50 -40 -30 -20 -10 0 10 20 30 40 50 60 70 80 90
degrees

FIG.9

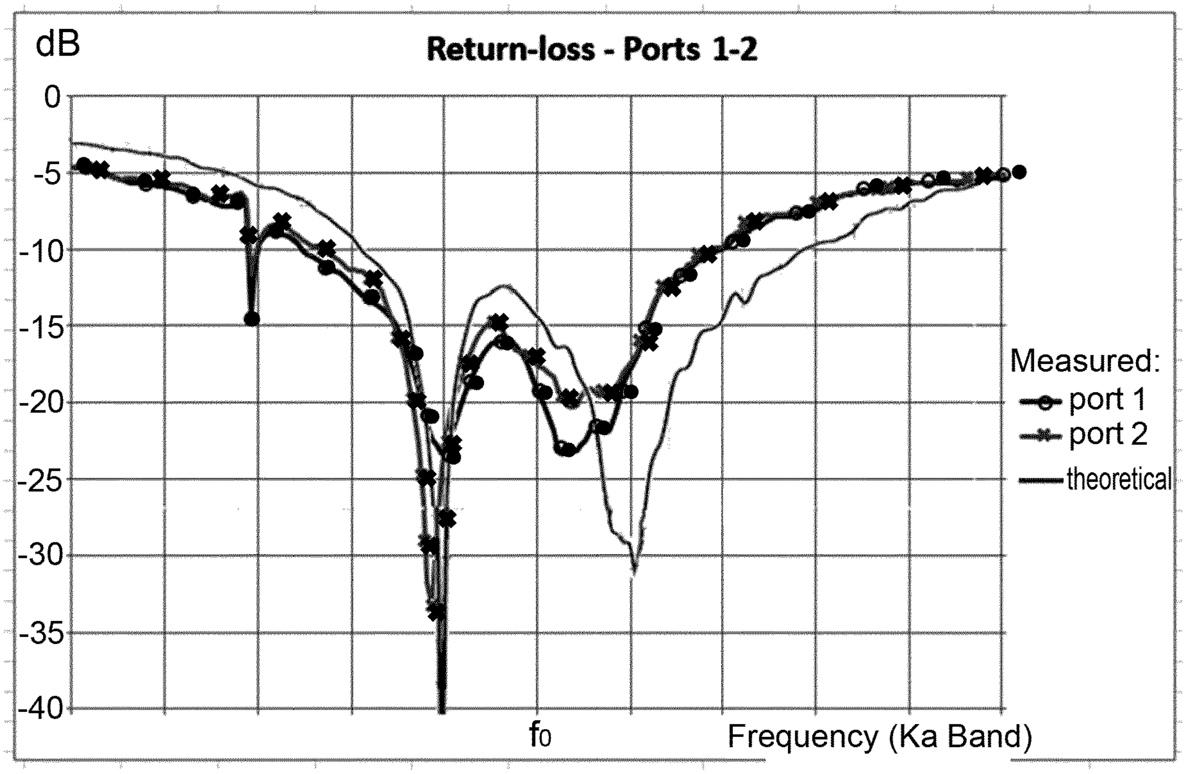

dB
Return-loss - Ports 1-2
0
-5
-10
-15
-20
-25
-30
-35
-40
Measured:
port 1
port 2
theoretical
f0
Frequency (Ka Band)

FIG.10

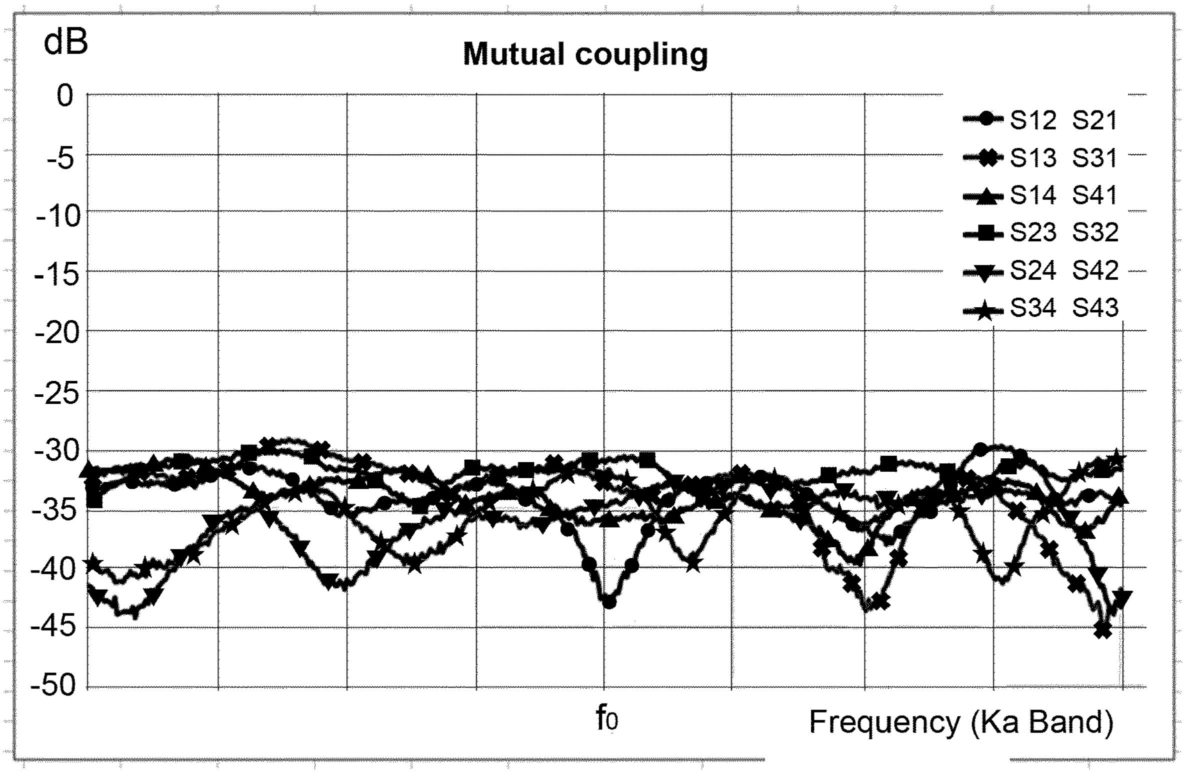

dB
Mutual coupling
0
-5
-10
-15
-20
-25
-30
-35
-40
-45
-50
S12 S21
S13 S31
S14 S41
S23 S32
S24 S42
S34 S43
f0
Frequency (Ka Band)

FIG.11

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EUROPEAN SEARCH REPORT

Application Number
EP 21 15 8613

DOCUMENTS CONSIDERED TO BE RELEVANT

Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X A	CN 109 742 556 A (UNIV SOUTHEAST) 10 May 2019 (2019-05-10) * figures 1, 8 *	1-9, 11-14 10	INV. H01Q1/38 H01Q25/02 G01S13/44
A	US 4 376 938 A (TOTH JOHN F ET AL) 15 March 1983 (1983-03-15) * figures 2A, 2B * * column 3, line 1 - line 5 * * column 3, line 30 - line 34 *	1-14	
A	US 5 831 581 A (KEOUGH SHAUN M [US]) 3 November 1998 (1998-11-03) * figures 1, 4-6 * * claim 1 * * column 1, line 21 - line 30 *	1-14	
			TECHNICAL FIELDS SEARCHED (IPC)
			H01Q G01S

The present search report has been drawn up for all claims

Place of search	Date of completion of the search	Examiner
The Hague	15 June 2021	Topak, Eray

3

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15-06-2021

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
CN 109742556 A	10-05-2019	CN 109742556 A	10-05-2019
		WO 2020151074 A1	30-07-2020
US 4376938 A	15-03-1983	NONE	
US 5831581 A	03-11-1998	DE 69703189 T2	17-05-2001
		EP 0825671 A2	25-02-1998
		IL 121568 A	26-07-2000
		US 5831581 A	03-11-1998

EPO FORM P0459

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Patent documents cited in the description

- US 4376938 A1, TOTH JOHN F **[0064]**
- US 5831581 A1 **[0064]**
- CN 109742556 A1 **[0064]**

Non-patent literature cited in the description

- **M. ELSHERBINY ; A. E. FATHY ; A. ROSEN ; G. HAYES ; S.M. PERLOW.** Holographic Antenna Concept, Analysis and Parameters. *IEEE Transactions on Antennas and Propagation,* March 2004, vol. 52 (3), 830-839 **[0064]**
- **G. MINATTI ; M. FAENZI ; E. MARTINI ; F. CAMINITA ; P. DE VITA ; D. GONZALEZ-OVEJERO ; M. SABBADINI ; S. MACI.** Modulated Metasurface Antennas for Space: Syntehsis, Analysis and Realizations. *IEEE Transactions on Antennas and Propagation,* April 2015, vol. 63 (4), 1288-1300 **[0064]**
- **P. DE VITA ; G. GUIDA ; M. BANDINELLI ; G. MINATTI ; M. SABBADINI ; E. MARTINI ; S. MACI ; A. FRENI.** Metasurface-by-design: an emerging concept for antennas and beam forming networks. *IEEE-APS Topical Conference on Antennas and Propagation in Wireless Communications (APWC),* 2013, 980-983 **[0064]**
- **G. MINATTI ; F. CAMINITA ; E. MARTINI ; M. SABBADINI ; S. MACI.** Synthesis of Modulated-Metasurface Antennas with amplitude, phase and polarization control. *IEEE Transactions on Antennas and Propagation,* September 2016, vol. 64 (9), 3907-3919 **[0064]**
- **D. GONZALES-OVEJERO ; G. MINATTI ; G. CHATTOPADHYAY ; S. MACI.** Multibeam by Metasurface Antennas. *IEEE Transactions on Antennas and Propagation,* June 2017, vol. 65 (6), 2923-2930 **[0064]**